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THERMAL PRINT HEAD MODULATION USING ADDITIVE COMPLEMENTS

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THERMAL PRINT HEAD MODULATION USING ADDITIVE COMPLEMENTS

FIELD OF THE INVENTION

5   The present invention relates to thermal printers, and more particularly to a method and apparatus for driving a thermal print head in a thermal printer.

BACKGROUND OF THE INVENTION

10   In a thermal printer for displaying a digital image, a thermal print head having a plurality of heaters is activated to transfer dye from a dye carrier medium to an image receiver such as paper. To achieve a continuous tone, the heaters in the thermal print head are modulated to transfer desired amounts of dye for each pixel in the image. The digital image is typically stored as a number of
15   lines of multi-bit pixels, where the value of each pixel represents the gradation value of the pixel. The task of modulating the print head involves converting the lines of multi-bit pixel values into a number of lines of single bit serial data which are sent to a shift register in the print head as shown in Fig. 3.

        A typical serial print head as illustrated in Fig. 3 has a number of
20   heating resistors **50** arranged in a linear array. The head also has a solid state serial input shift register **52**. The print head shown (as an example) has 512 resistors, and a single serial shift register that has 512 elements. Each shift register element acts as a digital switch, a 0 bit in the element will not close the switch, a 1 bit will. When the digital switch is closed, current flows from the DC
25   head voltage supply to the DC head ground when a printing pulse is applied. A resistor that is energized will heat up, and cause thermal dye to be deposited on the print.

        To energize the print head, a stream of 512 modulation bits must be clocked into the shift register **52**. One bit must be put into each shift register
30   element regardless whether that resistor will be turned on or not. Every time the

print head is to be energized, a stream of 512 modulation bits must be clocked into the shift register.

Known modulation methods include "Modulation by Comparison" and "Decrement Until Zero", which will be described below.

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Modulation by Comparison

One known method of producing serial modulation bits involves repeatedly comparing a pixel to an incrementally changing threshold value. This method has for example been discussed in US Patent 5,321,427 issued June 14,

10   1994 to Agar et al. The result of that comparison is used to produce an "on" or "off" modulation bit, normally represented by a one or a zero, respectively. In the example shown in Table I below, a 3-bit pixel with a gradation value of 5 is successively compared to the threshold values of 1 through 7, to produce 7 modulation bits (note that a 3-bit pixel can have any one of $2^3 = 8$ values between

15   0 and 7). If the pixel value is greater than or equal to the threshold, then the modulation bit is a "1", otherwise the modulation bit is a "0". The multi-bit pixel value of 5 produces five "1" bits and two "0" bits in this example.

Table I

	Modulation By Comparison						
Pixel Value	5	5	5	5	5	5	5
Threshold Value	1	2	3	4	5	6	7
Modulation Bit	1	1	1	1	1	0	0

20   **Decrement Until Zero**

Another method of producing a stream of serial modulation bits from multi-bit pixel values is to successively test each pixel value in a line to determine if it is non-zero. If a pixel's value is non-zero, its value is decremented by one and a "1" modulation bit is produced. The process is then repeated with

25   the decremented pixel values. When a decremented pixel value reaches zero, it is

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no longer decremented, and the modulation bit produced is a "0". As shown in Table II below, a pixel value of 5 is first determined to be non-zero, it is then decremented to 4, and a "1" modulation bit is produced. This is repeated 4 more times, until the pixel value has been decremented to 0. For the last 2 bits in the

5 example, the pixel value is already 0, so "0" modulation bits are produced, and the pixel value is no longer decremented. The multi-bit pixel value of 5 produces five "1" bits, and two "0" bits.

Table II

	Modulation by Decrement Until Zero						
Pixel Value (5)	5	4	3	2	1	0	0
Modulation Bit	1	1	1	1	1	0	0

10 Low cost digital signal processors (DSP's) are widely available for controlling consumer equipment. DSP's are easily custom programmable to perform operations such as print head modulation. Unfortunately, the Decrement until Zero and Comparison modulation methods both involve conditional operations which are very inefficient when implemented in software, thereby

15 hindering their use with DSP's. A compare operation must always be followed by a conditional operation based on the result of the comparison. A conditional operation typically requires multiple processor cycles to execute, which is inefficient and wastes processor cycles.

There is a need therefore for an improved modulation method for

20 thermal printers that can be more efficiently implemented in software for use in a programmable DSP.

SUMMARY OF THE INVENTION

The above noted needs are met according to the present invention

25 by a thermal print head in a thermal printer for printing a digital image, the digital image being composed of lines of multi-bit pixels, the print head having a

plurality of thermal resistors, adapted to be simultaneously addressed in parallel by a corresponding plurality of shift register elements, the print head being pulsed a plurality of times to print one line of the image. The print head is driven by providing a table of additive complement values, one additive complement value

5   for each of the possible values of a multi-bit pixel; successively adding a complement value to each of the pixel values in a line to obtain a number of sums corresponding to the number of pixels in the line, each sum having an overflow bit that is either "0" or "1", depending on the respective pixel value; loading the overflow bits to the shift register elements and applying a printing pulse to the

10   print head; and repeating the adding and loading steps for each complement value in the table.

There is a significant advantage achieved from using the present invention with an inexpensive programmable processor, as opposed to using a relatively more expensive custom integrated circuit. The advantage results from

15   the fact that by avoiding the use of a compare operation to determine if a modulation bit should be a "1" or a "0". The more computationally efficient algorithm of the present invention allows the use of a low cost DSP to perform the modulation task, thereby reducing the cost of the thermal printer.

The efficiency of the modulating process can be further improved

20   by accumulating a number of overflow bits in a multibit data word before sending them out to the print head as a group of modulation bits, thereby avoiding a plurality of multicycle instructions in the DSP program, compared to separately sending each single modulation bit to the print head.

Since the value and time placement of each modulation bit is

25   controlled by the value and placement of the additive complement values in the complement table, this method also has the advantage of providing for a high level of control over the characteristics of the produced serial bit stream..

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic diagram of a prior art thermal printing apparatus of the type which can be employed in accordance with the present invention;

Fig. 2 is a diagram showing a bit stream and a series of heating pulses useful in describing the invention;

Fig. 3 is a simplified diagram of a prior art thermal print head of the type in which the present invention can be employed;

Fig. 4 is a table illustrating the method of generating modulation bits by addition of additive complements according to the present invention;

Fig. 5 is a table showing a rearranged order of additive complements to distribute the modulation bits according to a preferred embodiment of the present invention;

Fig. 6 is a table showing the use of repeated additive complement values to obtain a non-linear response to the pixel values according to an alternative mode of practicing the present invention;

Fig. 7 is a diagram showing the position of an overflow bit after adding of a 6 bit pixel value and a 6 bit complement;

Fig. 8 is a diagram showing the placement of an overflow bit by adding of a 6 bit pixel value and a 10 bit complement;

Fig. 9 is a flow chart illustrating the steps of the method according to the present invention; and

Fig. 10 is a block diagram of an apparatus according to one embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to **Fig. 1**, there is shown in schematic form a thermal printing apparatus **10** which is adapted to print color images on a receiver member **12** from dyes transferred from a carrier member **14**. The receiver member **12**, in the form of a sheet is secured to a rotatable drum **16** which is mechanically

coupled to a drive mechanism **15**. It will be understood that the drive mechanism **15** includes a motor adapted to advance the drum **16** and receiver sheet **12**, under a thermal print head **18**. The print head **18** has a plurality of thermal heaters which press the carrier member **14** against the receiver sheet. The carrier member **14** is

5   shown in the form of a web and is driven from a supply roller **20** onto a take-up roller **22** by a drive mechanism **23** coupled to the take up roller **22**. The drive mechanisms **15** and **23** each include motors which continuously advance the carrier and receiver relative to the thermal heaters of the print head **18**.

        In operation, drive signals are continuously provided to the drive

10   mechanism **15** from a microcomputer control circuit **17** to rotate the drum **16** to bring successive, contiguous areas of the receiver sheet **12** into the print region opposite print head **18**. A portion of a dye frame is disposed between the print head **18** and the receiver sheet **12**. As noted above, these members are moved relative to the print head during the print operation. Printing pulses are supplied to

15   the thermal resistors of the print head **18** by print head control circuitry **24**, thereby heating the thermal resistors and causing dye to transfer from the carrier member **14** to the receiver **12**. In a preferred embodiment of the invention, the print head control circuitry 24 comprises a DSP, such as the TMS 320 LC 549 DSP available from Texas Instruments. DSP's of this type are widely available

20   and relatively inexpensive.

        The present invention performs the modulation task by producing a pulse count modulated stream of bits from a multi-bit pixel gradation value. According to the invention, the modulation bits are produced by repeatedly adding a series of constants to the pixel value, and using the overflows that are produced,

25   as the modulation bits.

        In a typical printing system, the number of modulation levels that can be produced by the print head is usually chosen to be an integral power of 2 (i.e. 64, 128, 256, etc.) The following description will discuss an implementation of the method of the present invention using 64 modulation levels, or 6-bit pixel

values. It will be understood that the invention is equally applicable to systems employing pixels having more or fewer bits.

In a 6-bit printing system, each pixel can have a gradation value of 0 through 63. An output bit stream for driving a thermal resistor in the print head
5   will have 63 bits representing 63 time periods where voltage pulses can be applied to the print head. A pixel value of zero will have all of the 63 bits set to zero, and no voltage pulses will be sent to the thermal resistor in the print head for printing that pixel. A pixel value of one will have one bit set to one, and 62 bits set to zero, so that only one voltage pulse will be sent to the print head for that pixel. A
10   pixel value of 2 will contain two bits that are set to one, etc. **Fig. 2** shows an . example of a bit stream that might be produced for a pixel value of 5. Note that all of the "1's", representing high pulses can, but don't necessarily have to be consecutive within the bit stream.

According to the present invention, a table is prepared that contains
15   63 different additive complement values. An additive complement is a number that is added to a pixel value, to test the magnitude of that value. The result of the addition will indicate if the pixel value being tested is less than a predetermined threshold, or if it is greater-than or equal-to the predetermined threshold. The result of the addition is irrelevant, but any overflow out of the sum produced in the
20   form of a 0 bit or a 1 bit, is the modulation bit that is sent to the print head to control the temperature of the corresponding heating resistor as shown in **Fig. 3**.

According to the method, these additive complements are successively added to the pixel value being modulated. Depending on the value of the additive complement, and the pixel value being modulated, the sum that is
25   produced will produce an overflow (a carry bit), or it won't. The overflow will always be a single bit, and if an overflow occurs, it will always place the single overflow bit into the next higher bit position above the most significant bit of the larger of the two numbers. This overflow bit is used as the modulation bit. Since this bit is produced by a simple binary addition operation, and does not require

any comparison or conditional operation, it is efficiently programmable in software, suitable for implementation in a DSP.

Table III in **Fig. 4** shows how this method would be used to generate a string of 7 modulation bits when the pixel value is 5. The table only
5   shows the first 7 bits in a string of 63 bits, it being understood that the remainder of the additions will produce "0" modulation bits. The first row across, labeled "Complement", contains the constants that are added to the pixel value of 5 to generated overflow bits. The values are shown for ease of understanding as decimal numbers, but it is to be understood that the values used in the program
10   will be binary numbers. The first five sums in the table produce an overflow (a "1" modulation bit), and the last two sums do not produce an overflow (a "0" modulation bit). The multi-bit value of 5 in a 6-bit pixel produces five "1" bits and 58 "0" bits. Similarly, a multi-bit value of 3 would produce three "1" bits, and 60 "0" bits, etc.

15   Often it is desirable to distribute the voltage pulses to the print head so that they are not all grouped together. Table IV in **Fig. 5** shows the same scenario as in Table III, with the exception that the value in the complement row have been arbitrarily rearranged. The result is that there are still five "1" bits, and 58 "0" bits in the modulation bit stream, but the "1's" have been scattered
20   throughout the bit stream. The exact distribution pattern of bits can be controlled by adjusting the arrangement of the complement values in the complement table.

A simple "linear" complement table would contain 63 different complement values, sequentially numbered from 63 down to 1. Using these values, a pixel value of 0 will not produce an overflow when added to any of these
25   values, so every modulation bit produced will be a "0" bit. A pixel value of 63 will produce an overflow when added to any of the complement values, so every modulation bit will be a "1".

If a value of 0 is inserted into the complement table, the resulting sum will always fit within 6 bits, and the overflow bit will always be zero. This
30   has the effect of imposing a maximum on the duty cycle that can be achieved. For

example, if roughly half of the values in the complement table were 0, the resulting bit stream could never have a duty cycle of over 50%. This provides a fast and efficient way to adjust the density of a printed line on the fly, e.g. as a result of image processing steps that might require that the current line to be

5   printed lighter.

Table V in **Fig. 6** shows the same scenario as in Fig. 4, with the exception that the first complement value of 63 has been repeated twice. In a table containing 63 complements, repeating certain entries would require that other entries won't exist in the table. This has the effect of producing a non-linear

10 response to the value of the pixel being modulated. The repeated complements will produce extra modulation bits for any pixel value that would have generated a modulation bit for that complement value.

This provides a fast and efficient way to adjust the density of a printed line on the fly, e.g. as a result of image processing steps that might require

15 that the current line to be printed darker. This method can also be used for compensating non-linear characteristics of the printing apparatus.

According to the invention the complement value in the complement table can have the same bit size as the pixel value, as shown in **Fig. 7**, so that after adding of the two values the overflow bit occurs in the next higher bit

20 position. Since the adding operation is carried out in the DSP, the resulting sum appears in a data register where the sum is been disregarded and only the overflow bit is to be sent to the print head as the modulation bit.

In some cases, it might be desirable that the overflow bit is generated at a preferred bit position within the data word to improve the efficiency

25 of the DSP program. This can be accomplished by making the bit size of the complement value larger than the bit size of the pixel value. In **Fig. 8** a 6 bit pixel value is shown that is added to a 10 bit complement. The overflow will then appear in the next higher bit position in the DSP register, in this example at the 11th bit. The 6 bit complement of Fig. 7 can easily be extended to a length of 10

30 bit by putting 4 "1" bits to the higher bit positions. If then an overflow occurs in

the lower 6 bits as in Fig. 7, this overflow will be carried on to the 11th bit. In this way, by extending the complement by the right number of "1" bits, the overflow, or modulation bit can be placed at any position to the left of the original 6 bit number within the DSP register.

5   The overflow bit has then to be read out from the DSP register and sent to the print head. A read instruction however, is a multicycle instruction which is very inefficient in a DSP program, as mentioned before. It would therefore be desirable to successively process a plurality of pixel values and to place the resulting plurality of overflow bits adjacent to each other into the DSP

10   register. This can be done by altering the bit length of the complement values in the complement table. The overflow bits can then commonly be read out and sent to the print head as a group of modulation bits, instead of separately reading out each single overflow bit. This saves many multicycle instructions, depending on how many modulation bits will be grouped together, and thereby further

15   increasing processing speed.

          Referring to **Fig. 9**, the method of the present invention will now be described. First, in step **26**, a table of additive complements is generated and stored in the memory of the DSP. As noted above, in a preferred embodiment of the invention, the complements are arranged such that the "1" bits will be

20   distributed throughout the pixel printing period. Next, in step **28**, the first line of pixel data of the image is retrieved from the image memory. The first complement is retrieved in step **30** from the table and added in step **32** to each pixel value in the first line of pixels to generate a line of overflow bits. The overflow bits are then sent to the shift register in print head **18** in step **34** and a

25   printing pulse is applied in step **36**. In step **38**, a check is then made to determine if the end of the table of complements has been reached. If not, in step **40** the next complement is retrieved from the table, and steps **32 -38** are repeated.

          If the end of the table of complements has been reached, a check is made in step **42** to determine if the end of the image has been reached. If not, the

next line of image pixels is retrieved, and steps **30 - 42** are repeated. If the end of the image has been reached, the process is ended in step **46**.

In **Fig. 10** one embodiment of the invention is illustrated in a block diagram. A digital image that comes from an electronic image source **62,** e.g. an

5   image digitizer, an optical disk storage device, a medical imaging modality, or the like is read line by line into a line buffer **64** under control of the DSP **60**. The DSP **60** reads the 6 bit pixel data of the image line stored in line buffer **64** and retrieves a complement value from the complement table **66**. The two binary values are added in the DSP and the resulting overflow bit is sent to the shift

10   register **52** in the print head **18.** This is repeated with all pixels in the image line until the shift register is completely loaded with modulation bits. A printing pulse is then applied to the print head to energize the addressed heating resistors **50.** A complete image line is printed when these steps have been repeated until the end of the complement table is reached. The next image line is then read by the DSP.

15   The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected by those skilled in the art without departing from the spirit and scope of the invention.

PARTS LIST

10	thermal printing apparatus
12	receiver member
14	carrier member
15	drive mechanism
16	rotatable drum
17	control circuit
18	print head
20	supply roller
22	take-up roller
23	drive mechanism
24	print head control circuit
26	generate table of additive complements step
28	get pixel data from first image line step
30	get first complement from table step
32	add complement to each pixel value in line step
34	send overflow bits to print head step
36	apply printing pulse step
38	check for end of table step
40	get next complement from table step
42	check for end of image step
44	get next line of image pixels step
46	end of image print step
50	heating resistors
52	serial shift register
60	Digital Signal Processor (DSP)
62	image source
64	line buffer
66	complement table
68	timing generator